Advanced Telemetry System for Indian Satellite Launch Vehicles - Qualification & Evaluation Strategies

P Kunhikrishnan & R Sethunadh
Vikram Sarabhai Space Centre, ISRO.P.O,
Thiruvananthapuram-695022, INDIA
Email : ***p_kunhikrishnan@vssc.gov.in, r_sethunadh@vssc.gov.in***

ABSTRACT

The advancements in electronic circuit design have resulted in miniaturization, field programmability and adaptability in almost every field of its application. Indian Space Research Organisation (ISRO) also has moved along with the advancements in electronic circuit design and packaging, resulting in the design of new generation launch vehicle avionics called Advanced Telemetry Systems (ATS) and Advanced Mission Computer systems (AMC). This has brought out weight reduction in avionics systems and subsequent enhancements in the launch vehicle payload capability. ATS is designed with state of the art devices to have performance improvements in terms of accuracy, programmability, weight reduction, power saving etc. It is designed to have configurable functional requirements like signal conditioning, signal processing, sensor excitation, bus monitoring, bus interfaces and telemetry formatting. These are realised in independent modules and are stacked together depending on the telemetry requirements of a particular stage of a launch vehicle to form an ATS stack. In the new telemetry system only sensors and RF systems are external to the ATS stack. This has resulted in a modular architecture with integration easiness and simplicity in powering scheme as power for each module is derived from an SMT DC-DC converter which is also a part of the ATS stack.

The qualification and flight acceptance level evaluation of these stacks are more challenging as it requires the simulation of different types and levels of inputs to various functional modules, acquiring the entire data and analysing the performance within the limited time available during different environmental tests. Verification of various interface standards used in different modules is addressed during the system level tests.

This paper brings out the qualification challenges of ATS for Satellite Launch Vehicle application starting from functional module level to final launch vehicle integration level tests. Also the performance improvements are discussed by comparing the telemetry data obtained from traditional telemetry system in earlier missions with advanced telemetry system flown in recent mission.

Key words: Advanced Telemetry System, programmability, Modular architecture, Qualification, Vehicle Integration Test, Performance improvements.

*Shri P. Kunhikrishnan is Associate Project Director, PSLV Project, Vikram Sarabhai Space Centre (VSSC), ISRO, Thiruvananthapuram-695022, INDIA.

# Shri. R. Sethunadh is Engineer-SE, Quality Division - Devices, Test & Evaluation, Systems Reliability, VSSC, ISRO, Thiruvananthapuram-695022, INDIA.

1. INTRODUCTION

Launch Vehicle Avionics consists of Navigation, Guidance & Control (NGC) systems and Telemetry, Tracking & Telecommand (TTC) systems. The advancements in electronic circuit design have resulted in miniaturization, field programmability, adaptability etc in almost every field of its application. Indian Space Research Organisation (ISRO) also has moved along with the advancements in electronic circuit design and packaging, resulting in the design of new generation launch vehicle avionics called Advanced Telemetry Systems (ATS) and Advanced Mission Computer systems (AMC). This has brought out weight reduction in avionics systems and subsequent enhancement in the launch vehicle payload capability. ATS was designed with state of the art devices to have performance improvements in terms of accuracy, programmability, adaptability, weight reduction, power saving etc.

The heart of any launch vehicle telemetry system is the pulse code modulator and controller, which controls various measuring units distributed over different stages of the launch vehicle. Depending upon the telemetry requirements of a particular mission, the controller formats the data from these units and does coding. The telemetry system also include data storage feature for storing the telemetry data during RF non-visibility to the ground stations. The stored data will be re-transmitted after gaining the visibility in order to avoid data loss. The 1553B bus-monitoring provision is also part of the new telemetry system for recording the bus transaction and reporting error, if any, in the Navigation, Guidance and Control communication link of the launch vehicle. These three functions have been realized in a single package called Integrated Control Unit (ICU). Signal conditioning and processing electronics which are made as different functional modules namely Data Acquisition Unit (DAU), Data Processing Unit (DPU), Advanced Signal Processing Unit (ASPU), Advanced Video Imaging System (VIS), Transducer Excitation Module (TEX) and SMT power module for powering these modules are also stacked with ICU to form a telemetry stack. Different stack configurations are used in various stages of the vehicle depending upon the measurement requirements of a particular mission. This has resulted in integration easiness and modularity of the onboard telemetry system of Indian launch vehicles. The old and new telemetry configurations are shown in figures 1 & 2 respectively.

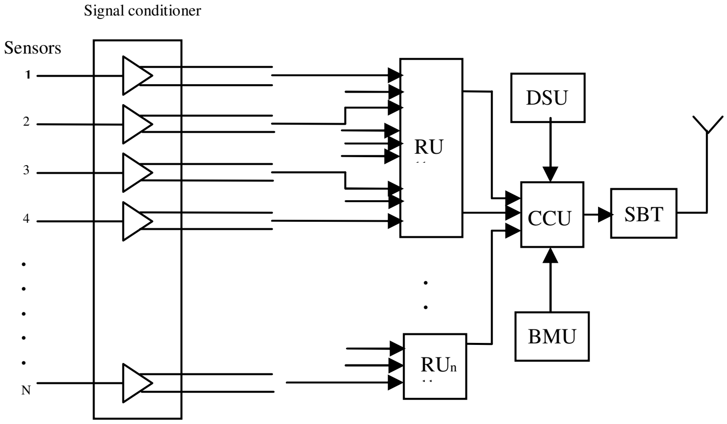


Figure 1. Configuration of old telemetry system

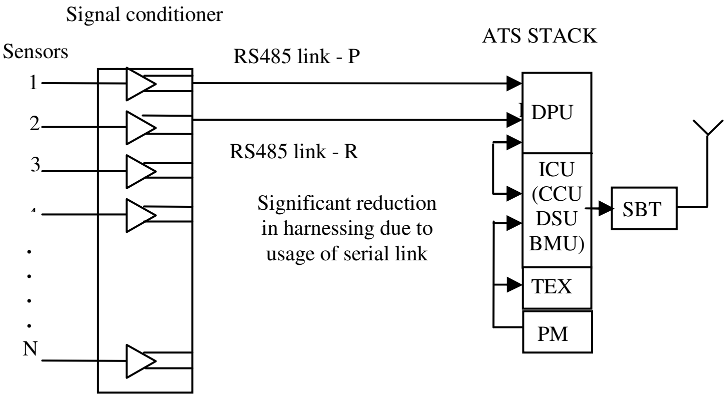


Figure 2. Configuration of new telemetry system

The stacking scheme has made the qualification and evaluation processes more challenging. This has necessitated simultaneous testing of all the functional modules in a stack in an integrated mode, especially with the limited time available during different environmental tests like thermal, vibration, EMI etc in the qualification and acceptance process.

Qualification tests are aimed to confirm the adequacy of the design of a particular system at an environment more severe by a specified factor or level than the worst of the expected flight or service environment. Flight acceptance tests are intended to confirm quality of manufacture of the system as per the qualified design and to uncover workmanship problems. Acceptance test levels are the worst of the expected service environments in actual flight or service.

2. QUALIFICATION & EVALUATION PROCESS

2.1 Qualification

Qualification tests are intended to demonstrate that the test item will function within performance specifications under simulated conditions more severe than those expected from ground and handling during launch operations. The main purpose of these tests is to uncover deficiencies in design and in the process of manufacture. These tests shall not exceed design safety margins or introduce unrealistic modes of failure within design specification.

Design qualification levels are in general fixed at the following levels with reference to the flight acceptance test levels.

- 1.5 times for peak amplitude vibration (grms) and shock.
- +3.5 db in acoustic/spectrum levels,
- 1.25 times the expected static acceleration
- +5°C in higher and -5°C in lower temperature ranges.

2.2 Acceptance level evaluation

Flight acceptance tests are performance verification tests on flight components and are indented to uncover infant mortality related failures and workmanship inadequacies in production process. The specifications for the above tests are drawn in such a way that if the components successfully undergo these tests, one can expect with satisfactory level of confidence that the component or subassembly will perform as per design during flight. The tests should be of sufficient duration and level so as to uncover possible component infant mortality due to workmanship inadequacies under this expected service environment.

The test levels are fixed at levels that are the worst expected during the actual flight and of sufficient duration equal to service condition or minimum required to uncover the workmanship errors, which ever is higher.

2.3 Test Environments

In the qualification and acceptance tests, different environmental conditions are simulated to cover the following three distinct service environments viz;

a) Ground environments including storage, ground handling and launch assembly
b) Atmospheric flight environments and
c) Space flight environments

The simulated ground environmental specifications are designed to qualify the package for storage, handling, transportation and pre-launch assembly conditions. Generally these tests are specified only for qualification process. The mechanical environment that experience during the transportation storage and mechanical installation phases are controlled so as to be less than the worst levels of subassemblies expected during actual flight. Necessary precautions are taken during storage to ensure that no degradation in performance occurs when storing the launch vehicle hardware for 2 years or more as may be specified by the user requirements.

Flight environmental tests are intended to evaluate the performance of the packages components and confirm the design or performance adequacy under simulated flight conditions. The actual test levels for the components may vary depending upon their location on the launch vehicle.

Space environmental tests are meant for upper stage systems and normally applicable to the payload and components or subsystems which are exposed to high vacuum and extreme low temperature during the launch phase till injection.

2.4 Test sequence

During the qualification process, different tests are conducted as per the test plan which comprises of test sequence, test procedure, acceptance criteria and performance limits for each of the functional modules. The performance limits are laid down as per the specification of each system with pre specified design margins.

All modules in the stack shall undergo different functional and performance tests immediately before and after a particular test. If the module is expected to be functional under similar environments in actual service conditions, the performance checks are carried out during the environmental test as well.

The following is the sequence followed for the qualification or acceptance test program.

1. Humidity tests
2. Hot soak
3. Cold soak
4. Operating hot soak
5. Shock tests /sine tests
6. Random vibration/acoustic tests
7. EMI tests.

Humidity Test

For propellant filling and checkout operations, the launch vehicle has to remain on the launch pad for a period of 8 to 10 hrs. During this period the vehicle and its sub systems are subjected to ground environments of wind, temperature, rain etc. The vehicle is designed to withstand these climatic environments. Humidity test is carried out to assess the resistance of components to high humidity conditions and variation of temperature cycle associated with humid conditions encountered in tropical areas, particularly those at the launch site. This test is conducted as per IS 8252 (Part 3) standard.

Thermal Tests

The thermal tests subject the modules to dry heat, cold and thermal shock environments. The dry heat test is carried out to ensure the performance of the modules, which are likely to be used at high temperature either in normal utilization or in storage. This test also verifies the influence of the variation of dielectric properties, thermal expansion etc. on the performance.

The cold soak test is intended to verify that the design ensures performance under extreme thermal conditions to which the modules are likely to be exposed during their life time.

Considering the long duration of operation of the electronic systems in the vehicle level, an operating soak test at 40 deg. C, 2hrs soak and 3 hrs operation is done for all critical ATS elements.

Sinusoidal vibration test

The objective of this test is to demonstrate the performance capabilities of modules or sub-assemblies under transient excitations caused by staging, engine ignition, engine shut off etc.

Random vibration test

Random vibration or acoustic tests are intended in particular to demonstrate the raggedness of the module or the sub assembly under high frequency excitations.

Shock test

Shock tests are indented to verify the resistance of the components to mechanical shocks by applying simple reproducible impulsive acceleration. This test is carried out using drop shock tester or simulating the shock in the vibration shaker system.

Prior to conducting of any of the above tests, the test item is operated under ambient conditions and a record of all data necessary to determine the performance is made. This data provides a basis for determining satisfactory performance in the subsequent tests conducted before, during and after environmental exposure.

The operation of the system shall be of sufficient duration or shall be repeated at appropriate intervals or number of times as may be required to ensure a comprehensive data for comparison with reference data.

2.4 Test Philosophy

When Advanced Telemetry System (ATS) was proposed for launch vehicles, testing of these avionics in different stages of integration was also addressed. Different functionalities are verified in the first level of T&E in the lab itself before integrating in to stacks for various subassemblies of vehicle. This helps in early detection of potential failures including interface related issues resulting in reduced turn around time. The different levels of testing employed for ATS are mentioned below.

2.4.1 Module level evaluation

Detailed functional performance verification of different ATS modules is conducted in the T&E lab. Here the thrust is given to the functional aspects of the module. The performance verification is done at Standard Room Condition (SRC), hot soak & cold soak Conditions.

2.4.2 Stack level evaluation

The cleared functional ATS modules, after module level evaluation are stacked together depending upon the measurement requirements of a particular stage of the launch vehicle. At this stage, during T &E, the different modules in the stack are interconnected as per the integration scheme of the vehicle. Here, thrust is given to the interface related issues of different modules along with its functional performance. Here, a long duration operating hot soak test, vibration test and EMI test are conducted. Since different modules are interconnected, this configuration is more realistic to the actual flight configuration. Here the challenge was to configure the test system in such a way that the simultaneous testing of all the functional modules in a stack in an integrated mode especially with the limited time available during different environmental tests like thermal, vibration, EMI etc was possible. Also with this configuration, the test time and resources are greatly saved as multiple modules are tested together.

2.4.3 Sub assembly level evaluation

End to end verification and calibration of each telemetry channel is carried out during this level of evaluation. The data obtained during this test is used for computing the scale factor of each channel. This scale factor is used during post flight data analysis to convert the digital data obtained from the telemetry system to the actual physical parameter in engineering units, measured onboard.

2.4.4 Integrated vehicle level tests

During the vehicle level integrated tests, the interfaces between different stages of the vehicle and the onboard system and ground checkout system are getting verified. By this level of evaluation, the ATS in the full flight configuration is tested before flight.

2.4.5 Piggy back flight test

Onboard functional verification with the minimal operational configuration is done at this level of evaluation. An ATS stack with minimum required modules and interfaces were integrated into the onboard telemetry system of one of the earlier PSLV missions as a piggy back module. The telemetry data measured using the system was transmitted to ground and was verified for the correct functionality of the ATS onboard.

2.4.6 Final flight test in an operational Vehicle

Full functional verification in the actual operational condition is done at this stage. Here the traditional telemetry system in the PSLV vehicle was replaced with the Advanced Telemetry System. The data obtained was verified for the proper functionality of each module and this data was compared with the traditional system. The performance improvement is explained in section 3.

2.5 Automated test system

When Advanced Telemetry System (ATS) was proposed, testing of these avionics with new generation ATE was also thought of. Towards this the pros and cons of different test system architectures were considered and finally we arrived at a configuration based on PXI/cPCI. Also before deciding this platform for our test system development we have made a comparative study on the traditional industrial PC based system and the new generation PXI system for selecting the better option in terms of technology, cost effectiveness, compactness and portability. The availability of all required equipments and interface modules in PXI/cPCI was one of the major considerations to extract the best benefit out of the new platform.

2.5.1 System Requirements

The major requirements of the test system include simulation of inputs to various functional modules using precision DC sources of varying amplitude and AC sources of varying amplitude and frequency. Also the test system shall cover 1553B bus communication with valid and error data, acquisition of PCM data and online analysis of the data by applying various input conditions and acceptance criteria, updating the error status and periodic monitoring of the power input, the final output and the checkout port output of the ATS stack and updating the display in near real-time, generating different pulsed commands to select the different modes of operation of the UUT etc. Testing the various functionality of the UUT has to be done in simultaneous and continuous mode with different inputs. Generation of test report and error reports and storage of raw test data are the other requirements. Selection of different stack configurations and acceptance criteria for different modules are also managed by the test system.

2.5.2 System Implementation

The increased complexity of the test system for different ATS Stacks is managed here with an ATE with a PXI system as its hardware platform and graphical programming environment of LabVIEW as the software platform. The ATE hardware was configured by using a PXI chassis and controller from M/s National Instruments with PXI/cPCI instrument modules from different vendors[1]. The simultaneous testing of multiple functionality of the system is tackled by providing greater parallelism in test while significantly decreasing the throughput overhead of the test system architecture.

2.5.3 System Hardware

The checkout hardware was configured by using a PXI chassis and a controller from National Instruments with PXI/cPCI instrument modules from different vendors. The PCM data acquisition module supports data rate up to 20 Mega bits per second as against the requirement of 2 Mbps. The 1553 B communication module supports the Remote Terminal (RT), Bus Controller (BC) & Bus Monitor (BM) modes of operation of 1553 B MIL-STD bus. The versatility of the PXI architecture and its compatibility with cPCI modules are evident from the multi-vendor support for the different instrument modules. The block schematic of the ATE is shown in Figure.3.

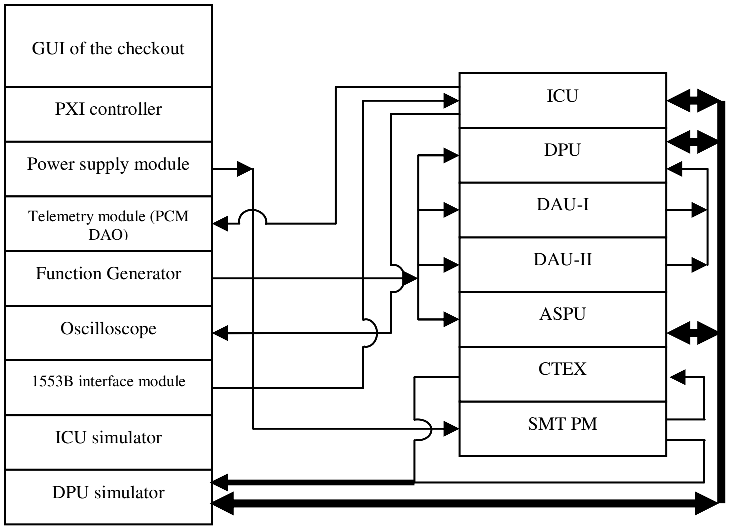


Figure 3. Block schematic of Advanced Telemetry System (ATS) checkout

2.5.4 System Software

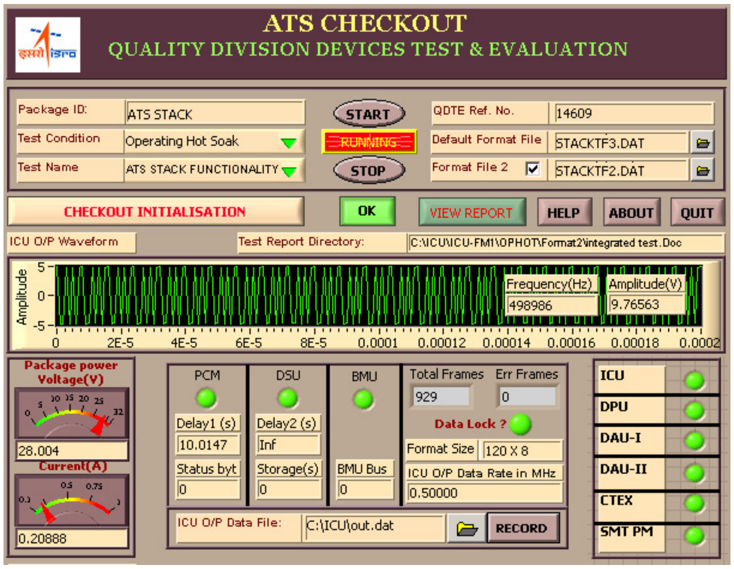
The software was developed using the graphical programming environment of LabVIEW-7 Express. Greater parallelism implemented using the multithreading architecture of LabVIEW has helped the simultaneous testing of various functionalities of different modules. The checkout software is highly modular and gives room for easy expansion. The modular architecture of the checkout allows easy expansion for making it a universal checkout system for testing other avionic packages in the telemetry chain[3].

The inherently easy-to-use nature of Express VIs in LabVIEW-7 Express has greatly helped in the software development. Also the Express VIs due to their interactive, configuration-based interface have helped in understanding, debugging and modifying the code during the development phase much easier. The maintenance of the system will become much simpler and transferable through this approach. Also the built-in measurement capabilities of LabVIEW have helped a lot in the development phase.

2.5.5 GUI of the Checkout

The Graphical User Interface (GUI) (shown in figure 2) of the checkout allows the user to select the stack configuration, entering the acceptance criteria, to select the test phase and different tests from a pull down menu etc. Also the test results are updated in the GUI in real time.

During the initialization phase the checkout will initialize all instrument modules and check its proper functionality. Once the checkout initialization is completed without any error, the checkout status window will show ‘Ready to start test’ status. The user can now select different test conditions viz. Initial Standard Room Condition (ISRC), operating hot soak, vibration-lateral, vibration-thrust, Shock, EMI etc and also different tests from the pull-down menu in the GUI and start the test. The selected test will keep on running in a continuous mode till the user stops it. During each test the number of frames tested and number of errors occurred along with the raw output data from the package will be updated in the display of the GUI in real-time. Also during the test the user can store the raw data in the hard disc of the system for a specified duration in a specified location given by the user by pressing the 'Record' button in the GUI. The errors in each functionality of the package will be indicated by the corresponding LED in the GUI during different tests. The telemetry data lock (with the frame sync pattern, sub frame ID and frame size) status will also be displayed in real-time. The Oscilloscope module in the ATE monitors the final output signal from the ICU and measures its amplitude and frequency and deviation if any will be prompted to the user while other tests are going on.



Package ID: ATS STACK
Test Condition: Operating Hot Soak
Test Name: ATS STACK FUNCTIONALITY
QDTE Ref. No.: 14609
Default Format File: STACKTF3.DAT
Format File 2 ☑: STACKTF2.DAT
Test Report Directory: C:\ICU\ICU-FM1\OPHOT\Format2\integrated test.Doc
Frequency(Hz): 498986
Amplitude(V): 9.76563
Voltage(V): 28.004
Current(A): 0.20888
Delay1 (s): 10.0147
Status byt: 0
Delay2 (s): Inf
Storage(s): 0
BMU Bus: 0
Total Frames: 929
Err Frames: 0
Format Size: 120 X 8
ICU O/P Data Rate in MHz: 0.50000
ICU O/P Data File: C:\ICU\out.dat

Figure 4. Graphical User Interface (GUI) of ATS checkout

Just after stopping any test, a consolidated report containing information on the total number of frames compared, total error frames with errors and deviations and the values of measured parameters like accuracy, delay duration, storage duration, re-transmission rate etc will be generated in MS Word format and stored in a directory structure automatically generated from the Package ID, Test condition and test name information. These consolidated reports are used at the end of test & evaluation phase for generating the final detailed test report of the system in a pre-defined format.

3. PERFORMANCE IMPROVEMENTS

The telemetry data obtained from the traditional telemetry system flown in one of the earlier PSLV missions and that of the advanced telemetry system flown in the recent PSLV mission were compared. The performance improvements in the telemetry data, due to the induction of ATS is clearly evident from the plots. This improvement was basically due to the employment of high performance sigma delta converters in the data acquisition systems. The highly stable excitation voltages generated through TEX for different transducers have also contributed for this. A typical telemetry parameter acquired through ATS during the recent PSLV flight is shown below for reference and comparison.

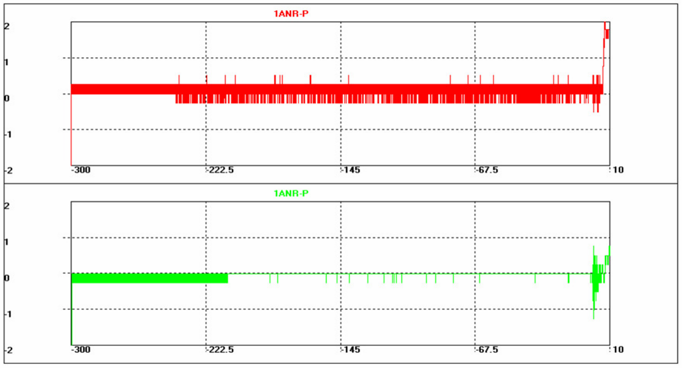


Figure 5. A typical parameter acquired using old & new t/m system

4. CONCLUSION

The qualification challenges of ATS for Satellite Launch Vehicle application is explained starting from functional module level to final launch vehicle integration level tests. The test philosophy and the complexity of the test system are highlighted. The modular instrumentation architecture based ATE proved to be effective for ATS testing because it defines an industrial computing platform that clearly leverages the technology advancements of the mainstream PC industry. Also the performance improvements are discussed by comparing the telemetry data obtained from traditional telemetry system in earlier missions with advanced telemetry system flown in recent mission.

5. REFERENCES

[1] The PXI modular instrumentation architecture: PXI white paper.

[2] Sethunadh R, “Using new instrument interface standards to increase automatic test system performance” Proceedings of IEEE AUTOTESTCON-2005, 0-7803-9101-2/05 pp667-682

[3] Sethunadh R, Pradeepkumar N S, Kunhikrishnan P, & S Selvaraju, “Test & Evaluation Methodology for Integrated Telemetry Avionics of Indian Launch Vehicle” Proceedings of ReQUEST-2008

[4] Sethunadh R, et al, “Virtual Instrumentation techniques in test & evaluation of Launch vehicle avionics” Published in Defense Science Journal, Vol.52, No.4 October 2002. pp 357-362.

[5] Sethunadh R, et al, “Virtual Instrumentation system results in faster testing of launch vehicle telemetry avionics” Published in the proceedings of virtual instrumentation system conference 2001 by M/s National instruments. Available at: http://www.ni.com/aerospace/avionics.htm

Abbreviations

ATE	Automatic Test Equipment
PCI	Peripheral Component Interconnect
VXI	VME Extension for Instrumentation
PXI	PCI Extension for Instrumentation
cPCI	Compact PCI
ATS	Advanced Telemetry System
EMI	Electro Magnetic Interference
RFI	Radio Frequency Interference
USB	Universal Serial Bus
LXI	LAN Extension for Instrumentation
IIS	Instrument Interface Standards
ICU	Integrated Control Unit
DPU	Data Processing Units
UUT	Unit Under Test